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HIGHWAY RESEARCH REPORT

INVESTIGATION OF LOSSES ASSOCIATED WITH PRETENSIONED GIRDERS

STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 636383

Prepared in Cooperation with the U.S. Department of Transportation, Bureau of Public Roads July, 1968

STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, *Governor*

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

July 1968

Report M & R No. 636383

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

INVESTIGATION OF LOSSES

ASSOCIATED WITH PRETENSIONED GIRDERS

ERIC F. NORDLIN
Principle Investigator

W. H. AMES
Co-Investigator

Assisted By
R. Elliott
W. E. Faist
M. H. Johnson
R. R. Trimble

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

ABSTRACT

REFERENCE: Nordlin, E. F., Ames, W. H., "Investigation of Losses Associated with Pretensioned Girders", State of California, Department of Public Works, Division of Highways, Materials and Research Department. Research Report 636383, July 1968.

ABSTRACT: A study was initiated to determine quantitative allowances for stress loss in pretensioned members stressed with 270 ksi wire strand. This was to be accomplished by casting and instrumenting three "typical" precast pretensioned I girders. Based on a survey of prestressing plants which indicated that stress losses are peculiar to particular stressing systems, it was concluded that evaluation of "typical" girders, particularly under laboratory controlled conditions, would not result in the development of universal stress loss allowances; therefore, the originally planned work on this project was discontinued. This report summarizes the plant investigation procedures used and the findings made during the survey of prestressing plants engaged in production of bridge members in California. During the course of this investigation, it was clearly revealed that the higher the "lockoff" (anchorage) force, the greater the resulting steel creep loss.

KEY WORDS: Stressing, losses, allowances, prestressing, prestressed concrete, steel wire, instrumentation, creep.

ACKNOWLEDGEMENTS

This study was accomplished in cooperation with the United States Department of Transportation, Federal Highway Administration, Bureau of Public Roads, as Item D-4-40 of Work Program HPR 1(4). The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

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INTRODUCTION

This project was initiated to determine quantitatively a more realistic allowance for stress loss in pretensioned members stressed with 270 ksi wire strand. Under current California highway design specifications, the loss in stress in pretensioned prestressing steel due to creep and shrinkage of concrete, creep of steel, and elastic compression of concrete is assumed to be 35,000 pounds per square inch of prestressing steel. The accuracy of this stress loss allowance for pretensioned concrete bridge girders fabricated with 1/2" 7-wire (270 ksi) prestressing strand is questionable. Furthermore, no convenient and practical method had been devised to determine actual stress losses that occur during fabrication and from point-to-point within a stressing system.

The original work plan called for the casting and instrumentation of three "typical" precast pretensioned I girders to isolate and measure creep in the prestressing steel, creep in the concrete, concrete shrinkage, and elastic shortening, thereby determining the relative significance of these stress loss factors.

Since methods of fabrication were found to vary considerably among manufacturers who supply California highway contracts with precast pretensioned bridge members, it was concluded that significant stress losses might well be attributed to peculiarities of a particular fabrication system. A thorough survey of the prestressing plants was initiated in an attempt to determine the extent of stress losses due to steel creep, harping methods, stressing procedures, stressing bed construction, etc. Six prestressed concrete manufacturing plants which supply bridge members to California highway contracts were visited. At each of these plants it was found that there are losses peculiar to each system for which no specific allowances are made in the structural design. Therefore, it was concluded that casting of "typical" girders would not fulfill the original intent of establishing stress loss allowances at the subject plants, and work on this project was discontinued.

During the course of this project, an instrument known as the strand stress beam was developed under a State sponsored research project (Ref. 1). This instrument is designed to enable the inspector on pretensioned bridge members to readily determine the stress adjacent to points of suspected high friction loss in a prestressing strand within the girder limits, thereby revealing locations and magnitude of stress losses within any given system. With this information as an inspection guide, proper adjustments can be made to assure that the stress at any point within a member fulfills the design requirements. Since the objective of this project was to enable more accurate determination of stress losses in pretensioned wire strand, regardless of plant procedures, development of the strand stress beam rendered continuation of this project unnecessary.

This report summarizes the plant investigation procedures followed and findings of the survey of the subject prestressing plants.

FINDINGS

All the prestressing plants surveyed were found to have difficulty in obtaining the design stress in harped strands. Some of the difficulty may be attributed to the lack of provision of a positive type of adjustment at the strand anchorage. A positive screw or threaded type device can be used to permit accurate and convenient adjustment of strand forces at any time prior to concrete placement. The main difficulty, however, appears to be excessive friction at harping points due to the design of hold downs and the stressing-harping sequence followed. Further frictional as well as concrete placement problems are created when the space limitations, usually dictated by the design of the member, require bundling of the prestressing strands.

The stress losses revealed by the plant survey prompted some of the manufacturers to improve those procedures which were shown to significantly contribute to stress loss. However, with the exception of anchorage seating losses (a relatively minor loss on long beds), only one manufacturer had made any allowance in his stress calculations for other losses. Generally the only allowance made in stress calculations for losses was the 3% specified by the California Standard Specifications dated July 1964 which is intended only to compensate for small variations in temperature, in reading of stressing equipment, and in material's properties such as modulus, strength, etc.

Stress losses were found to be so great in some pretensioning beds that strand anchored at 70% of the ultimate strength had dropped to less than 60% at the time the concrete was cast. This study also indicates that in the 70% range of stress level, small increases in anchorage "lockoff" force result in significant increases in prestressing strand creep losses, thereby emphasizing the importance of the specification requirement limiting the stress to a maximum of 70% of the guaranteed ultimate strand tensile strength.

CONCLUSIONS

1. A universal allowance for stress losses in pretensioned prestressed concrete is unrealistic when applied to the various systems commonly used in the production of precast prestressed bridge members in California, unless measures are taken to minimize frictional stress losses due to methods of harping, stressing, and anchorage.

2. Much care should be taken to assure adherence to the maximum allowable anchorage stress (70% of the guaranteed ultimate tensile strength) to minimize stress loss due to creep of the prestressing strand.

3. Care should be taken in design to minimize problems created by tight dimensions that may require bundling of strands, particularly where they are to be harped.

4. A positive screw or threaded type device should be provided at the strand anchorage to permit accurate and convenient adjustment of the strand force at any time prior to concrete placement.

5. Ultimately the contractor or manufacturer should be required to provide a stressing system that holds stress losses to a specified minimum, with the burden of proof, as his responsibility, through a proven accurate method of stress determination at any point within the bridge member. As an alternate the manufacturer should be required to identify stress losses peculiar to his particular stressing system and to compensate for any excessive or intolerable losses by the provision of additional prestressing strand.

DISCUSSION

A. Force Checking Techniques

The equipment used for checking forces in this study includes compression load cells, tensile load cells, and a device developed, during the course of this study, by the Materials and Research Department known as a strand stress beam (Ref. 1). The checking procedure followed was to compare actual forces in the prestressing strand with design requirements and with the manufacturer's assumptions and calculations by instrumentation of the pretensioning bed during a normal or simulated production run.

Generally, compression load cells were placed on several strands at the jacking and/or opposite end of the strand. In addition, if possible, two tensile cells were placed on a harped strand at a critical location. When the strand stress beam became available, the stress in all strands in a given pattern (harped and straight) were checked.

A compression load cell placed on a straight (relatively friction free) strand assured consistency in forces in all the other straight strands in a given member by using the same jacking pressure as that observed when the strand with the load cell was stressed. The cell was placed on the jacking end of the strand to enable the operator to observe the hydraulic gage and load cell readout simultaneously while the stressing was in progress. The load cell on straight strand also served as a control to evaluate the stress variations due to temperature on all strands whether harped or straight.

The primary location used to determine the stress on all strands is at the center of the girder span since this is the location of the maximum simple span moment used to determine the working force. It is impractical to instrument at the centerline, however, since bundling of the harped strand is permitted. Furthermore, this practice prevents use of the stress bar in this area. Neither is it economical to use splice cells at the centerline, as there is no chance of recovery when actual production work is in progress.

B. Steel Creep

During the course of this investigation, an important relationship between anchorage stress level and strand creep loss was revealed. It was shown that the higher the "lockoff" (anchorage) force, the greater the strand creep loss. An average of stress measurements in four tests conducted on 100 ft. undeflected strands at a prestress yard showed that with an anchorage "lockoff" force of 28,100 lbs. on a 1/2" diameter 270 ksi strand (68% of guaranteed minimum ultimate tensile strength), the creep loss was approximately

2% in 72 hours. At an anchorage "lockoff" force of 30,100 lbs. (73% of guaranteed minimum ultimate tensile strength), the creep loss was approximately 4% in 72 hours. It therefore appears that, in this stress range, small increases in the anchorage force result in significant increases in steel creep losses. Therefore, prohibiting anchorage "lockoff" forces greater than 70% of the guaranteed ultimate tensile strength should be rigidly adhered to, as called for in California's current specifications.

It also appears that the rate of stress application may have a significant effect on steel creep. In one prestress yard, where stressing forces are applied in a relatively rapid manner, high creep losses were observed. In another yard, where stressing forces are applied at a much slower rate, creep losses were lower. Comparing other features of the stressing systems at these two plants, it appears that the most likely cause of the variation in measured creep loss is due to the difference in the strand loading rates.

C. Strand Chucks

Strand chucks (Figure 1) are available in sizes corresponding to the size of prestressing strand used. Observations at the various prestress plants indicate that, for proper operation, strand chucks should have a service program which includes frequent rotation through a routine cleaning and checking cycle. The checking should include culling out chucks with damaged cases and replacement of cracked or worn grippers. The cleaning cycle should include the soaking of entirely disassembled chucks in solvent, brushing or buffing, and relubrication.

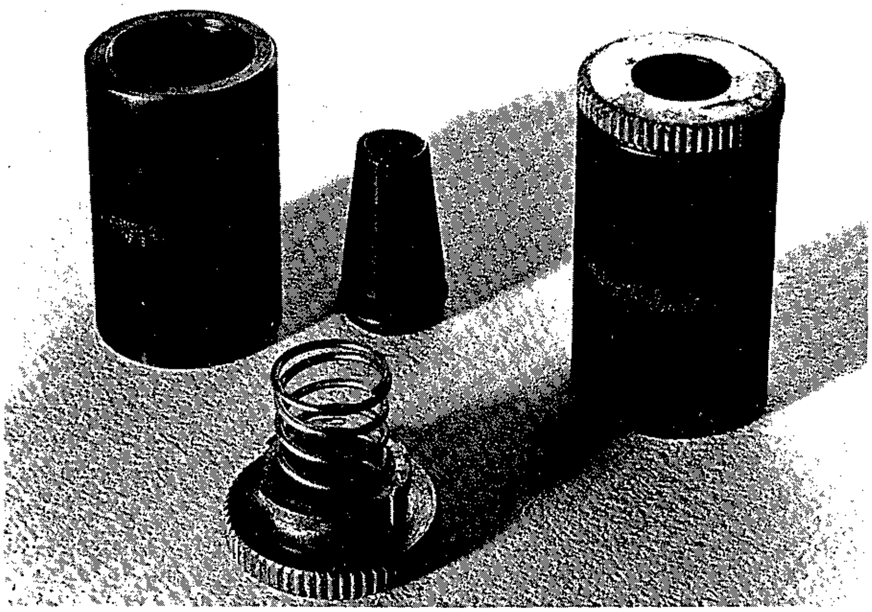

Figure 1
Strand Chuck

Stress losses in the anchorage system after initial seating of the grips has taken place appear to be negligible; however, the initial seating loss may be from 1/4" to 5/8". Seating losses of this magnitude are generally not very significant on a long bed, but cannot be ignored on short beds. If a stressing bed is extremely short, the loss in seating can be overcome without exceeding the maximum allowable temporary jacking stress (75% of minimum ultimate under current California specifications) by shimming after stressing.

Seating losses in harped strands usually take place in the increment between the anchorages at the jacking end and the first harping point due to the frictional resistance. It is therefore important to realize that if a load cell is placed on the jacking end it will show a greater loss than has actually occurred throughout the remainder of the strand.

D. Stressing and Harping Methods

Basically there are two stressing methods, single strand and multi-strand. Single strand (Figure 2) consists of applying the load to individual strands with a center hole or yoke type hydraulic jack. Multi-strand stressing (Figure 3) is performed by anchoring a number of strands to a movable bulkhead, applying a load to that bulkhead from jacks mounted on a stationary bulkhead, thereby stressing the strands simultaneously. In California practice multi-strand stressing is used almost exclusively on the straight strands in the pattern while harped strands are usually stressed individually.

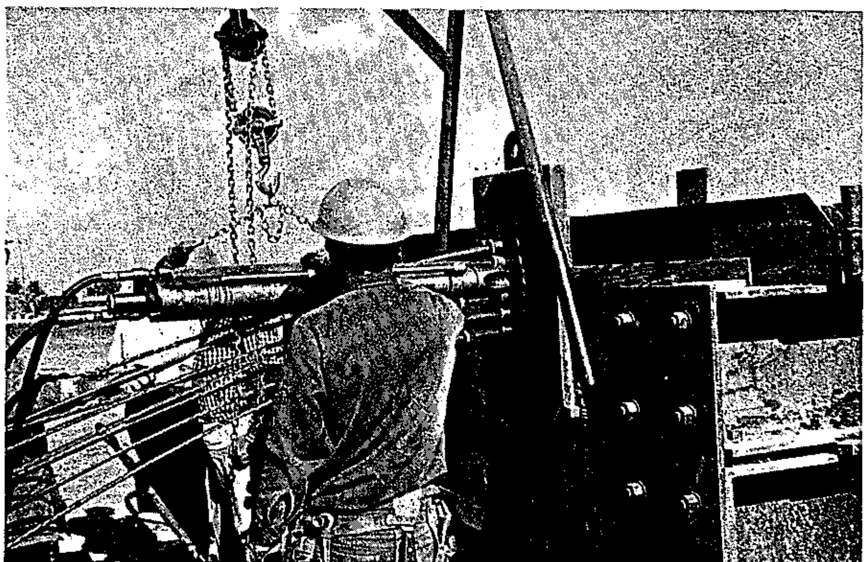

Figure 2
Typical single strand stressing operation.

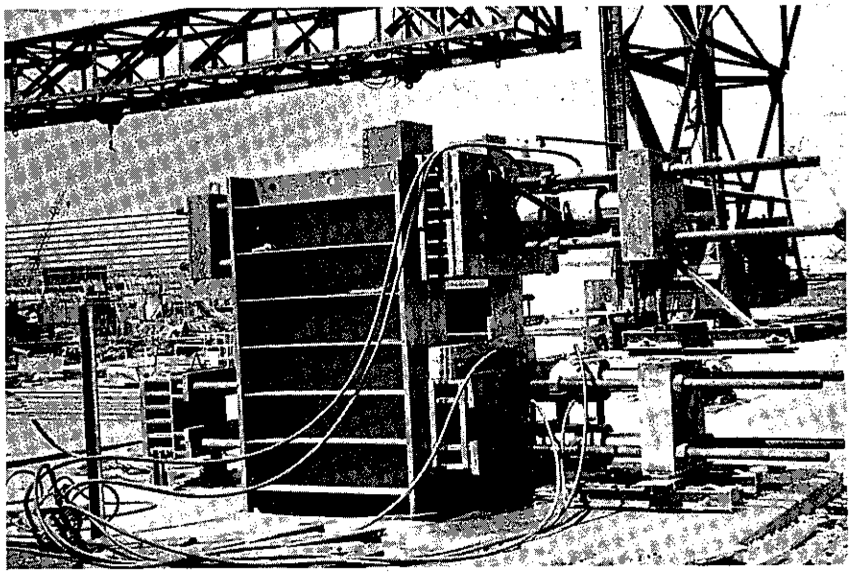

Figure 3
Typical multi-strand stressing operation.

For purposes of this project harping systems were classified in the broad categories shown in Figure 4. Preharped is the term used when all of the harped strands are placed into the stressing bed in their final configuration before stressing. Partially preharped refers to systems in which harped strands are held in their final configuration at some harping points prior to stressing and are then deflected to their final configuration at other locations after partial stressing. Fully post-harped is a system in which all of the harped strands are partially stressed in a straight position and then are deflected to their final configuration after stressing.

Bundling of strands (Figure 5) is undesirable in preharped or partially preharped systems because of the excessive frictional losses caused by interaction between the strands during stressing and the difficulty in obtaining sound, dense concrete around and between all strands.

When a fully post-harped system is used, there is no disadvantage to bundling of harped strands from the standpoint of frictional losses, provided the strands are harped simultaneously.

When bundling is used with either the preharped or partially preharped systems, care must be taken throughout the stressing operation to carefully control the order of stressing to avoid

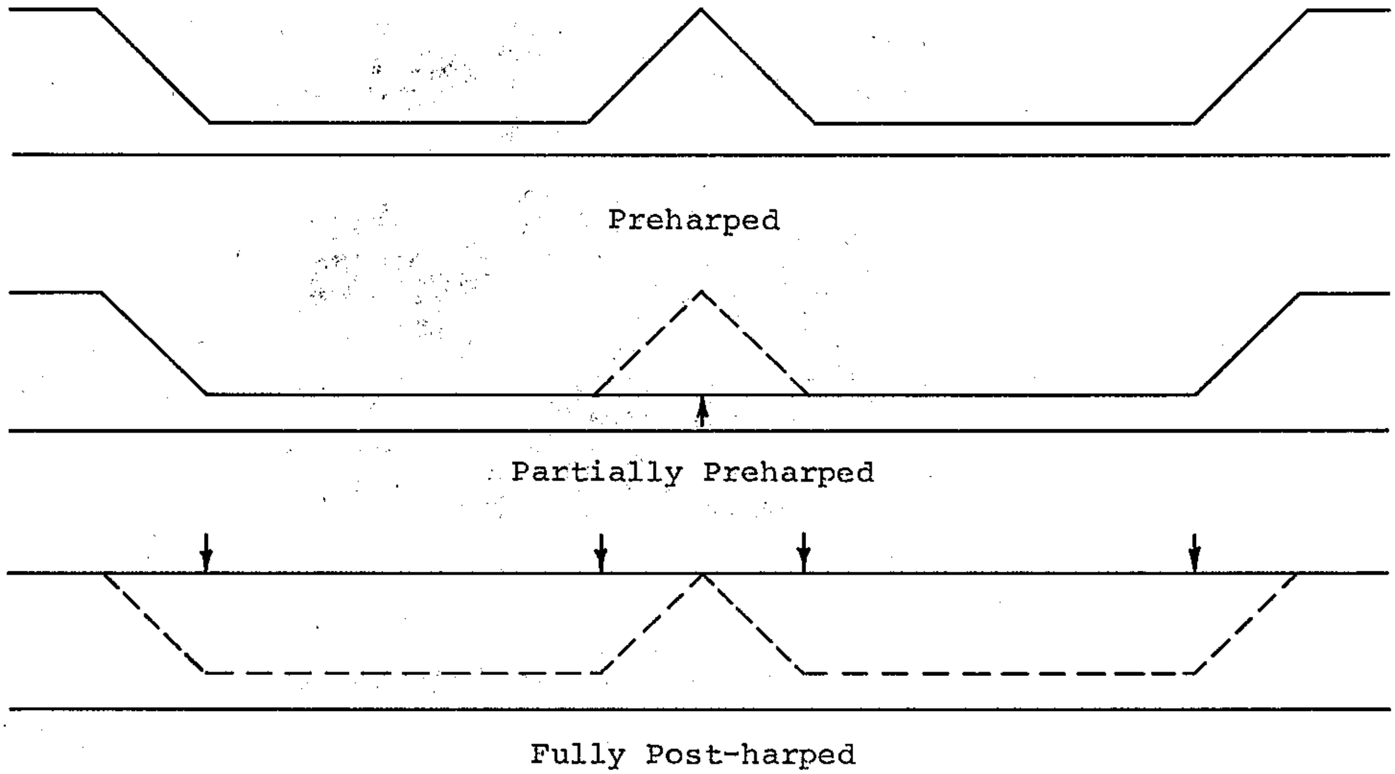

Figure 4
Harped strand configuration
for two in line stressing bed.

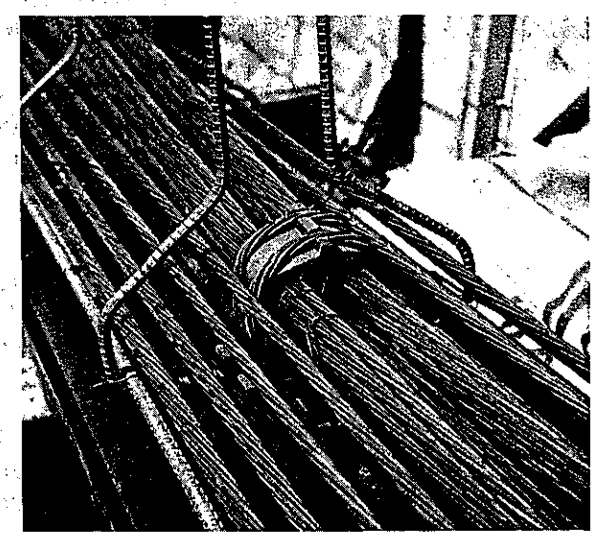

Figure 5
Bundling of strands. Note the
intimate contact of the strands.

excessive frictional losses. With either system, when bundling is used, the fewer the strands that are bundled the more assurance there is of satisfying design requirements.

When using a preharped or partially preharped system, the best harping hardware to use is a relatively friction-free type, such as those shown in Figure 6. Lubrication of harping points is also helpful in keeping friction to a minimum but requires careful cleaning prior to placing concrete. Even with such precautions, frictional problems arise frequently when more than one girder is cast "in-line". If friction due to in-line casting cannot be overcome, the addition of more prestressing steel is advisable in order to obtain the required working force. In some cases jacking from both ends will minimize frictional losses and improve the reliability of working forces obtained by in-line casting. Striking of the hold downs should not be allowed as a friction relieving method, due to the uncertainties involved in its effectiveness and possible damage to the strand tendons.

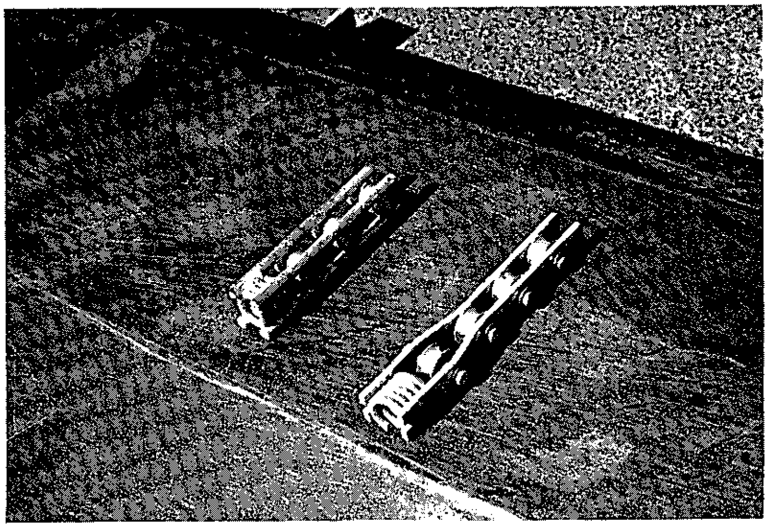

Figure 6
Relatively friction-free hold downs.

E. Stressing Bed Construction

At the majority of the plants investigated, the stressing bulkheads are independently anchored. Under these conditions there is no significant differential movement between the bulkheads due to temperature changes, thus essentially eliminating the need for any adjustments in stressing computations.

Another stressing bed system that was observed consisted of an assembly of large steel beams in which thermal changes must be considered, particularly when temperature ranges are significant.

In any case all factors that might affect the stressing forces, including the type of stressing bed, climatic exposure, harping method, temperature differential in both the stressing bed and strand, anchorages, stressing sequence, etc. should be carefully considered in determining the acceptability of the prestressing system and the final product.

REFERENCES

1. Nordlin, E. F., Ames, W. H., and Post, E. R., "Method to Determine the Axial Tensile Force in High Strength Prestressing Strand", Research Report 646322, April 1968, State of California, Department of Public Works, Division of Highways, Materials and Research Department, Sacramento, California.